

Calcium in Mercury's Exosphere: Modeling MESSENGER Data

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Mercury is surrounded by a surface-bounded exosphere comprised of atomic species including hydrogen, sodium, potassium, calcium, magnesium, and likely oxygen. Because it is collisionless, the exosphere's composition represents a balance of the active source and loss processes. The Mercury Atmospheric and Surface Composition Spectrometer (MASCS) on the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft has made high-spatial-resolution observations of sodium, calcium, and magnesium near Mercury's surface and in the extended, anti-sunward direction. The most striking feature of these data has been the substantial differences in the spatial distribution of each species. Our modeling demonstrates that these differences cannot be due to post-ejection dynamics such as differences in photo-ionization rate and radiation pressure, but instead point to differences in the source mechanisms and regions on the surface from which each is ejected.

The observations of calcium have revealed a strong dawn/dusk asymmetry, with the abundance over the dawn hemisphere significantly greater than over the dusk. To understand this asymmetry, we use a Monte Carlo model of Mercury's exosphere that we developed to track the motions of exospheric neutrals under the influence of gravity and radiation pressure. Ca atoms can be ejected directly from the surface or produced in a molecular exosphere (e.g., one consisting of CaO). Particles are removed from the system if they stick to the surface or escape from the model region of interest (within 15 Mercury radii). Photoionization reduces the final weighting given to each particle when simulating the Ca radiance.

Preliminary results suggest a high temperature ($1-2 \times 10^4$ K) source of atomic Ca concentrated over the dawn hemisphere. The high temperature is consistent with the dissociation of CaO in a near-surface exosphere with scale height ≤ 100 km, which imparts ~ 2 eV to the freshly produced Ca atom. This source region and energy are consistent with data from the three MESSENGER flybys; whether this holds true for the data obtained in orbit is under investigation.

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Abstract

Although neutral calcium was discovered from ground-based observations of Mercury's exosphere, the first high-spatial-resolution observations were made by the MESSENGER spacecraft. The Monte Carlo model of the exosphere we have developed to simulate the observations from the Mercury flybys and early orbits suggests a high-energy source of Ca concentrated in the dawn, equatorial region.

1. Introduction

Mercury is surrounded by a surface-bounded exosphere comprised of atomic species that include hydrogen, sodium, potassium, calcium, magnesium, and likely oxygen. Because it is collisionless with atoms on ballistic trajectories, the exosphere is of a composition that represents a balance among the active source and loss processes.

The Mercury Atmospheric and Surface Composition Spectrometer (MASCS) on the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft has made high-spatial-resolution observations of sodium, calcium, and magnesium near Mercury's surface and in the extended, antisunward-directed tail [1-3]. The most striking feature of these data has been the substantial differences in the spatial distribution of each species. Our modeling demonstrates that these differences cannot be due to post-ejection dynamics such as differences in photo-ionization rate and radiation pressure, but instead point to differences in the source mechanisms and regions on the surface from which each is ejected. In this paper, we discuss the MASCS observations of calcium from the flybys and MESSENGER orbital phase and consider possible calcium source mechanisms.

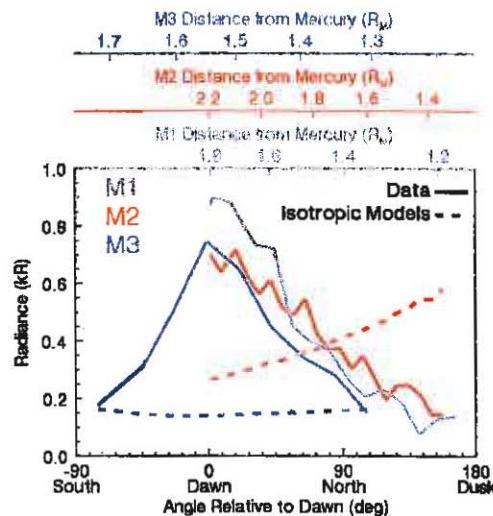


Figure 1: Calcium observed over Mercury's nightside during the three MESSENGER flybys (solid lines). The broken lines indicate simulated emission from a source isotropically distributed over the surface. R_M is Mercury's radius.

2. Observations

MASCS regularly observes resonantly scattered Ca emission at 422.7 nm. Unfortunately, because of observational constraints (MASCS always looks within 10° of perpendicular to the Sun-Mercury line) and the differing observing priorities of each MESSENGER instrument, the possible viewing geometries are limited and can vary substantially from orbit to orbit. The published data from the flybys suggests a strong dawn/dusk asymmetry in the calcium distribution, with the abundance over the dawn hemisphere

significantly greater than over the dusk. The data in Figure 1 were obtained as MESSENGER passed through Mercury's shadow near closest approach during each of the three Mercury flybys [1-3]. The space-craft executed a roll maneuver that allowed MASCS to measure latitudinal variations in the exosphere. The broken lines indicate the distributions expected from isotropic sources. For all three flybys, MASCS observed an excess of emission when MASCS was pointed in the equatorial plane toward dawn compared to dusk.

3. Modeling

We have developed a Monte Carlo model of Mercury's exosphere to track the motions of exospheric neutrals under the influence of gravity and radiation pressure [4]. Ca atoms can be ejected directly from the surface or produced in a molecular exosphere (e.g., one consisting of CaO). Particles are removed from the system if they stick to the surface or escape from the model region of interest (within 15 Mercury radii). Photoionization reduces the final weighting given to each particle when simulating the Ca radiance.

Preliminary results suggest a high temperature ($\sim 1 - 2 \times 10^4$ K) source of atomic Ca concentrated over the dawn hemisphere (Figure 2). The high temperature is consistent with the dissociation of CaO in a near-surface exosphere with scale height $\lesssim 100$ km, which imparts ~ 2 eV to the freshly produced Ca atom. This source region and energy are consistent with data from the three MESSENGER flybys; whether this holds true for the data obtained in orbit is under investigation.

4. Summary and Conclusions

The MASCS observations of Mercury's exosphere obtained during the flybys suggests a persistent, high-temperature source of calcium over the dawn hemisphere. The high temperature is consistent with dissociation of CaO in a closely confined exosphere; however, it is not clear why this material would be localized to the dawn region. Possible explanations include the production and build-up of Ca or CaO on the nightside due to cold-trapping of material produced on the dayside, implantation of solar wind or magnetospheric calcium ions on the nightside, or ion-induced chemistry. Observations made while MESSENGER orbits Mercury will help us determine the persistence of this feature and whether other exospheric species exhibit similar behavior.

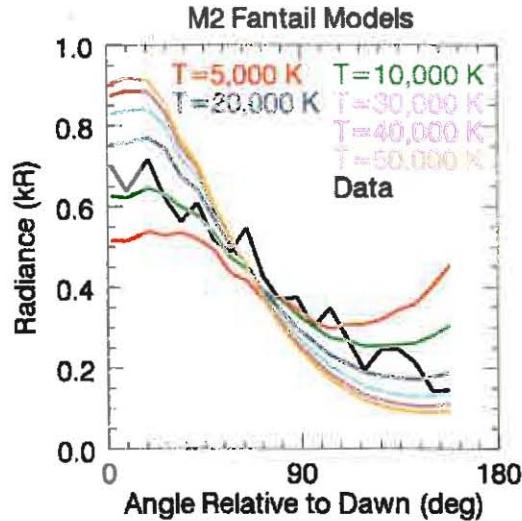


Figure 2: Comparison of MASCS data from MESSENGER's second Mercury flyby with a modeled Ca source confined closely to the dawn equatorial point. Lines correspond to sources with Maxwellian energy distributions at the indicated temperatures.

Acknowledgements

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